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MEMORANDUM

PITCH-UP PROBLEM - A CRITERION AND METHOD OF EVALUATION

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SUMMARY

A method has been described for predicting the probable relative severity of pitch-up of a new airplane design prior to initial flight tests. An illustrative example has been presented which demonstrated the use of this procedure for evaluating the pitch-up behavior of a large, relatively flexible airplane. It has also been shown that for airplanes for which a mild pitch-up tendency is predicted, the wing and tail loads likely to be encountered in pitch-up maneuvers would not assume critical values, even for pilots unfamiliar with pitch-up.

INTRODUCTION

One of the stability problems of concern to airplane design and operational groups in recent years is pitch-up or an inadvertent stalling tendency that usually occurs well below the maximum lift capabilities of an airplane. This pitch-up behavior, insofar as the pilot is concerned, restricts the useful maneuvering range of an airplane since accelerated flight near the pitch-up region may result in unintentional stalls and spins at low dynamic pressures and in excessive airframe loads at high dynamic pressures. One of the important factors contributing to pitch-up is the destabilizing trend in the variation of pitching moment with lift, which is characteristic of airplane configurations with swept wings or horizontal tails placed well above the extended wing-chord plane. Since high-speed performance considerations have generally resulted in the use of these configurations, most current high-performance airplanes exhibit a pitch-up tendency in varying degree. This paper is concerned with two aspects of the pitch-up problem of interest to airplane design and operational groups. First, a method is briefly outlined for assessing the probable relative severity of pitch-up prior to actual flight tests. Even though this method was designed primarily for evaluation of fighter airplanes, its extension to larger, relatively flexible airplanes is demonstrated by means of an illustrative example. Second, the loads aspects of the pitch-up problem are discussed with particular reference to the possibility of exceeding the design wing and horizontal-tail loads in pitch-up maneuvers.

SYMBOLS

C_L	airplane lift coefficient
$C_{L,max}$	maximum lift coefficient
C_m	airplane pitching-moment coefficient
C_{m_α}	pitching-moment-curve slope
F_s	pilot control force, lb
g	acceleration due to gravity, 32.2 ft/sec^2
I_Y	airplane pitching moment of inertia, lb-ft-sec^2
L_t	maneuvering horizontal-tail load, $I_Y\ddot{\theta}/l_t$, lb
l_t	horizontal-tail length, ft
m	airplane mass, lb-sec^2/ft
n	airplane load factor, g units
q	dynamic pressure, lb/sq ft
V	airplane velocity, ft/sec
W	airplane weight, lb
M	Mach number
$M(\alpha)$	curve defining variation of airplane pitching moment with α, ft-lb
$M_{\dot{\alpha}}$	damping due to $\dot{\alpha}$, ft-lb/radian/sec
M_δ	control-surface moment effectiveness, ft-lb/radian
$M_{\dot{\theta}}$	damping due to $\dot{\theta}$, ft-lb/radian/sec
$Z(\alpha)$	curve defining variation of airplane normal force with α, lb
Z_δ	control surface lift effectiveness at constant α, lb/radian

α airplane angle of attack, deg or radians

θ airplane pitch angle, radians

γ airplane flight-path angle, radians

δ control surface deflection, deg or radians

δ_e elevator deflection, deg

$\dot{\delta}_{rec}$ recovery control rate, deg/sec

$\ddot{\theta}$ airplane pitching acceleration, radians/sec^2

A dot over a symbol denotes the derivative with respect to time.

DISCUSSION

Before outlining methods for assessing the pitch-up behavior of a new airplane design, the pitch-up characteristics of two existing airplanes will first be examined in order to illustrate the basic problem. In figure 1, an experimental time history, representative of a swept-wing medium bomber with a mild pitch-up tendency, is shown. Figure 2 presents a typical time history of a severe pitch-up experienced with a swept-wing fighter airplane. The Mach numbers for these maneuvers were 0.8 at 35,000 feet for the bomber and 0.9 at 35,000 feet for the fighter. The various quantities plotted in these two figures serve to define completely the pitch-up characteristics of these two airplanes and include the pilot control force and position inputs and the airplane angle-of-attack, load-factor, and pitching-acceleration responses. An inspection of these time histories indicates that a severe pitch-up is characterized by large inadvertent increases in angle of attack of 10° or more, by a corresponding increase in load factor of about 25 percent of the design load, and by the extremely large recovery transient (shown by the peak negative pitching acceleration) which resulted from the pilot's applying large and rapid corrective-control inputs in an attempt to minimize the overshoots. For the medium bomber, an attitude overshoot of less than 2° and a load-factor overshoot of about 10 percent of the design load are shown. Also, corrective control was applied at a rather leisurely rate of 3°/sec, and the resulting recovery transient was fairly mild. For the fighter airplane (fig. 2), the pilot's comments indicated that the pitch-up was abrupt and relatively uncontrollable and that maneuvers above the pitch-up boundary would generally result in inadvertent stalling, in possible spin entry, and in exceeding the desired load factor considerably. For the medium bomber (fig. 1), the pitch-up was described as mild, but with some tendency to exceed the desired load factor. The reversal in the stick-force gradient above the pitch-up boundary was considered objectionable by the pilots, but they still felt that they had considerable control over the peak attitudes and load factors developed during pitch-up.

METHOD OF EVALUATION

In order to determine analytically from available wind-tunnel data the relative severity of pitch-up of a new airplane design prior to actual flight experience, both a rational method for predicting the airplane response during pitch-up and a criterion relating this response to pilot opinion must be established. The former requirement may be satisfied by defining a standard evaluation maneuver based on control inputs that are likely to be used by pilots in pitch-up maneuvers. Figure 3 illustrates the three stages in which this synthesized maneuver is assumed to occur. The first stage is an initial control ramp corresponding to a certain entry load-factor rate into the pitch-up region. (For the present study, this rate was fixed at about 0.5g per second.) The second stage is essentially a time interval equal to the pilot's response time between his initial perception of pitch-up and his application of corrective control. In the third stage, the pilot is assumed to apply corrective control to the forward stop at various rates to check the pitch-up. Before this standardized maneuver can be constructed, it is first necessary to determine an airplane response quantity which the pilot associates with the onset of pitch-up and a reasonable response time. From inspection of time histories of pitch-up maneuvers obtained in flight and from ground tests in a pitch simulator, it was found that the pilot associated onset of pitch-up with a threshold level of pitching acceleration of about 0.15 radian/sec^2. An average response time of about 0.4 second was also determined. This information, together with basic wind-tunnel data, may then be used to synthesize the model evaluation maneuver and to compute the desired response quantities, which include pitch acceleration and the angle-of-attack and load-factor overshoots.

In order to establish a criterion relating pertinent computed response quantities in pitch-up maneuvers to pilot opinion, this synthesized pitch-up maneuver was applied to six airplanes which exhibited pitch-up tendencies ranging from mild to severe, according to NASA pilots who flew these airplanes. The basic aerodynamic data for these airplanes and the equations of motions used in the computations are shown in figure 4. Airplanes A and B are swept-wing fighter airplanes with elevator control. Airplanes C, D, and E are swept-wing fighter airplanes with all-movable stabilizers. Airplane F is a swept-wing medium bomber with elevator control. Computations were made for these six reference airplanes at a Mach number of about 0.9, since flight tests indicated that the pitch-up was most severe at this speed. Also, computations were performed for each airplane at two altitudes: 35,000 feet, which was the altitude at which most of the research flight experience was obtained with these airplanes, and at lower altitudes where the pitch-up region was assumed entered in a 6g maneuver for the fighters and in a 3g maneuver for the bomber. Before the results of the computations are presented, the objectives of a criterion based on these computed results should be noted. They are as follows:

(1) The criterion should validate the computational procedure based on the synthesized pitch-up evaluation maneuver.

(2) The criterion should then enable design or operational groups to assess the severity of pitch-up of a given design relative to that of six existing reference airplanes already evaluated by NASA pilots.

(3) The criterion should provide some information relating the magnitude of the overshoots to the pilots' control response initiating the recovery phase of the pitch-up maneuver. (As will be noted subsequently, this is of importance in assessing the probability of critical tail loads being encountered in pitch-ups.)

The primary results of the computations are presented in figure 5 where the computed overshoots at an altitude of 35,000 feet and a Mach number of about 0.9 are related to numerical pilot-opinion ratings obtained during flight evaluations of the six reference airplanes. These results are given for a relatively low recovery control rate of 10°/sec because it was found that the pilots based their opinions on the overshoots associated with these low rates rather than the maximum that they were capable of applying. The pitch-up rating schedule used during the flight evaluation is explained in table I. It is shown in figure 5 that a good correlation exists between the magnitudes of the overshoots and the results of flight evaluations, and this agreement lends some confidence to the computational procedure used. For example, airplanes A and B with α overshoots in excess of about 11° were assigned unsatisfactory ratings of 8 and 7, respectively. As noted in table I, these ratings are reserved for airplanes with a relatively severe pitch-up for which there is an increased tendency for the pilot to apply large, abrupt corrective control. On the other hand, airplanes E and F with an α overshoot generally under 4° were assigned a marginally satisfactory rating of 2 which implies a mild, barely perceptible pitch-up with little tendency for the pilot to apply extreme corrective control to check the pitch-up. By comparing the critical computed overshoots with the corresponding values for these six reference airplanes, design and operational groups are also provided with a method for assessing the probable relative severity of pitch-up of a new design. Applied in this manner, the method is also useful for determining the modulating effects of aerodynamic modifications or automatic control devices on a given design. Also, if the pilot rating schedule in table I or the results presented in time-history form in figures 1 and 2 are referred to, it is noted that as the magnitude of the computed overshoots increases and pilot opinion deteriorates, the pilot corrective-control response tends to become more extreme and results in violent recovery transients and increased maneuvering tail loads.

ILLUSTRATIVE EXAMPLE

To illustrate the use of this method in evaluating the pitch-up behavior of a large airplane, the procedure used for the medium swept-wing bomber will be examined. For large flexible airplanes of this type, the computational procedure was different in two important respects from that used for the fighters. First, since the computed pitching acceleration did not build up to the threshold value established from simulator and flight tests of fighters, it was found necessary to alter the standard evaluation maneuver. This was accomplished by assuming that the pilot initially perceives pitch-up at an angle of attack corresponding to the initial sharp destabilizing break in the pitching-moment curve - in this case, where the airplane stability first reduces to zero. Second, it was found that the effects of flexibility had an important bearing on the computed pitch-up behavior of this airplane. For example, as shown in figure 6, neglecting these effects by using rigid-model pitching-moment data resulted in a computed α overshoot of about 8°. This value compares rather poorly with the actual value of about 2° computed for the flexible airplane. The point to be made here is that for large flexible airplanes, the effects of flexibility, particularly those on the airplane pitching-moment curve, must be properly accounted for before a reasonable prediction of pitch-up behavior can be attempted.

A word of caution should be injected here. Since the rating schedule shown in table I was used primarily for fighters, there may be some question of its applicability to transport types. NASA pilots who have flown both fighters and transports feel that transport requirements should be somewhat more severe than those for fighters because of additional considerations for passenger comfort and lower design load factors. They have indicated, tentatively, that acceptable transport ratings would fall in the range of 0 to 2, rather than the 0 to 5 range noted for the fighters in the table. This implies that only a mild pitch-up, comparable to that observed for the swept-wing medium bomber, would be considered acceptable for jet-transport airplanes. However, the actual range of acceptable behavior for transports would have to be defined by the appropriate certifying agency.

LOADS ASPECTS OF THE PITCH-UP PROBLEM

It was noted previously that one facet of the pitch-up problem of concern to operational groups was the possibility of inadvertently exceeding the design wing and tail loads in pitch-up maneuvers. This possibility is examined first at the relatively high altitude of 35,000 feet where the pitch-up region is entered at load factors well under design values for the six airplanes considered in this study. In figure 7, bar graphs of the computed peak load factors and maneuvering tail loads are shown for the two airplanes rated unsatisfactory by the pilots - airplanes A and B - and for the two airplanes rated marginally satisfactory - airplanes E and F. Results are presented for two recovery control rates in each case, a relatively low rate of 10°/sec and the maximum rates possible. The load-factor overshoots and maneuvering tail loads for these four example airplanes are shown by the shaded areas in this graph. Note that the tail loads have been nondimensionalized by dividing by the airplane weight. It is evident from these results that the loads problem is not likely to be critical in pitch-up maneuvers encountered at these flight conditions. The maximum load factors, even for airplanes with relatively severe pitch-up tendencies, remain well under design values, due either to $C_{L,max}$ limitations or to the reduced lift-curve slope characteristic of these airplanes in the pitch-up region. Similarly, the maneuvering tail loads do not attain critical values due either to typical limitations imposed by the forward control stop or to the maximum recovery control rates available on these airplanes.

The more critical flight conditions at lower altitudes and higher dynamic pressures where the pitch-up region is entered at load factors close to design levels are examined next. In this case, it might be expected that both the wing and tail loads may assume critical values. To illustrate this, the results of computations where the pitch-up region is entered at about 80 percent of the design load factor, that is, about 6g for the fighter types and 3g for the bomber airplane, are presented in figure 8 for the four example airplanes. It may be seen from these results that the pilot is faced with a difficult problem, particularly if he penetrates the pitch-up region at this flight condition with an airplane with a moderately severe pitch-up tendency. If he attempts to check the pitch-up with high recovery control rates, the wing loads in excess of design values are minimized, but at the expense of the maneuvering tail loads exceeding design levels. On the other hand, if relatively low recovery control rates are used, the wing loads tend to exceed the design load considerably. For the two airplanes whose pitch-up behavior was considered fairly mild by the pilots at 35,000 feet, the overshoots, even for these critical flight conditions, are relatively small and unaffected by recovery control rate. For this reason, in addition to the reduced probability of extreme recovery control rates being applied to check mild pitch-up tendencies, the possibility of exceeding the design tail loads in pitch-up maneuvers, even for pilots relatively inexperienced with pitch-up, is considered fairly remote.

CONCLUDING REMARKS

A method has been described for predicting the probable relative severity of pitch-up of a new airplane design prior to initial flight tests. An illustrative example has been presented which demonstrated the use of this procedure for evaluating the pitch-up behavior of a large, relatively flexible airplane. It has also been shown that for airplanes for which a mild pitch-up tendency is predicted, the wing and tail loads likely to be encountered in pitch-up maneuvers would not assume critical values, even for pilots unfamiliar with pitch-up.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Nov. 5, 1958

REFERENCE

1. Sadoff, Melvin, Matteson, Frederick H., and Van Dyke, Rudolph D., Jr.: The Effect of Blunt-Trailing-Edge Modifications on the High-Speed Stability and Control Characteristics of a Swept-Wing Fighter Airplane. NACA RM A54C31, 1954.

TABLE I.- PILOT RATING OF PITCH-UP

Adjective rating	Numerical rating	Description
Satisfactory	0	Satisfies stability and control requirements
Marginally satisfactory	1 2	Pitch-up barely perceptible - little tendency for pilot to apply rapid and excessive corrective control
Unsatisfactory but acceptable	3 4 5	Pitch-up is more apparent - there may be some tendency for the pilot to apply rapid and perhaps excessive corrective control
Unsatisfactory	6 7 8	Pitch-up severe ranging from controllable only with greatest difficulty to practically uncontrollable - increased tendency for the pilot to apply rapid and excessive corrective control
Unacceptable	9 10	Pitch-up so severe that airplane is uncontrollable - some possibility of entering a spin or other unusual maneuver from which recovery may be difficult or impossible

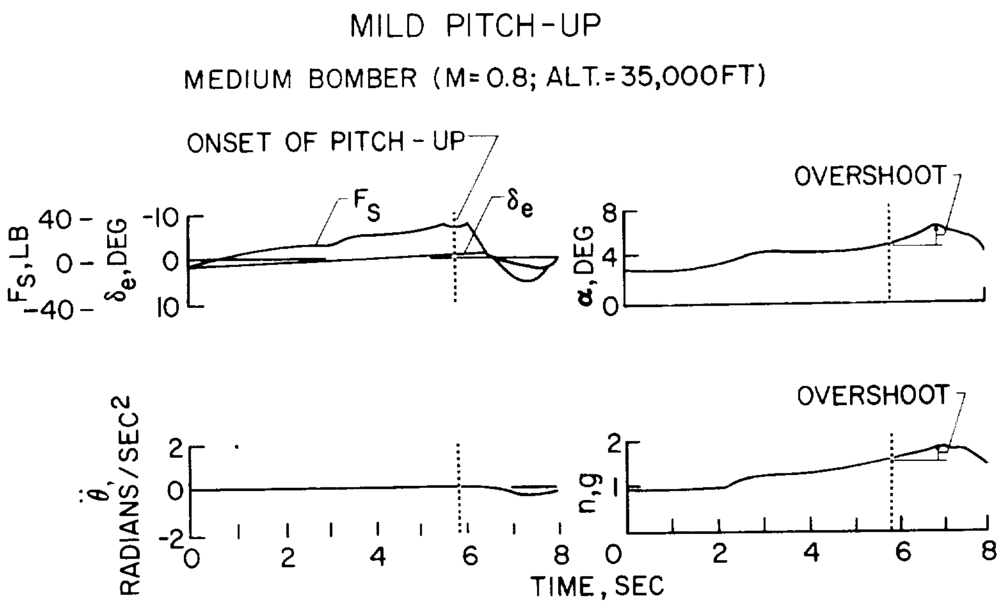

Figure 1

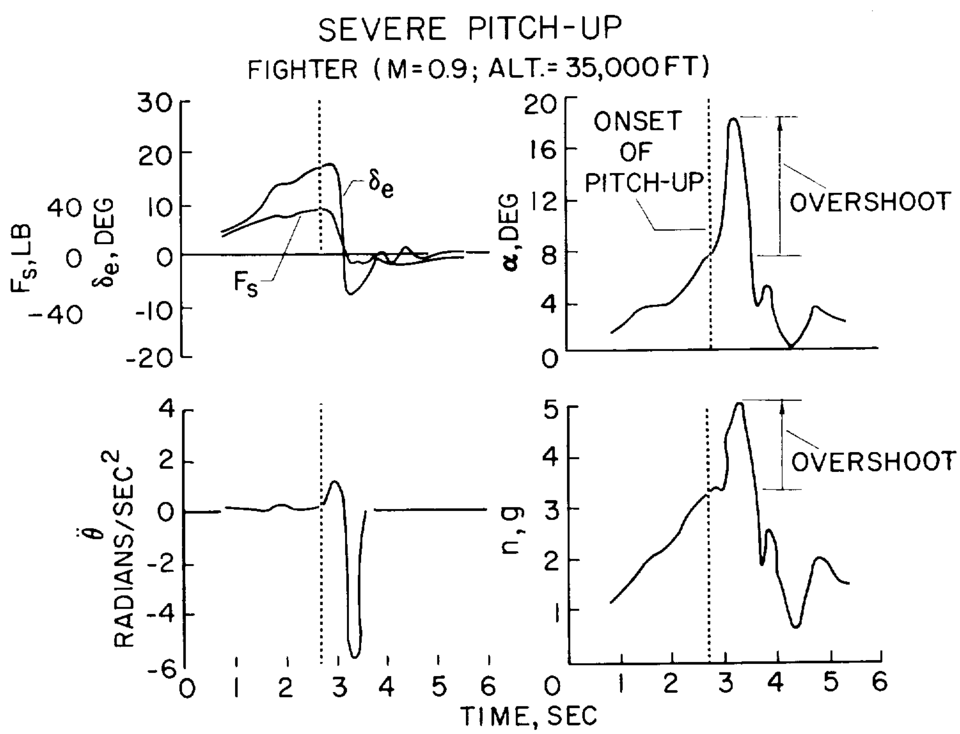

Figure 2

SYNTHESIZED PITCH-UP MANEUVER

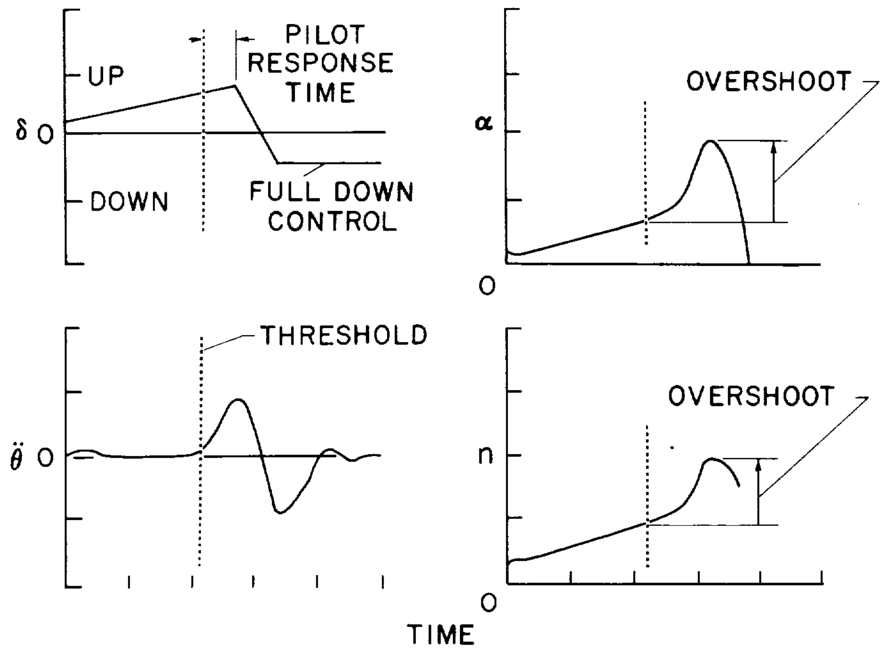

Figure 3

BASIC AERODYNAMIC DATA
FOR SIX REFERENCE AIRPLANES

EQUATIONS OF MOTION: $-mV\dot{\gamma} = Z(\alpha) + Z_\delta \delta$

$I_Y \ddot{\theta} = M(\alpha) + M_{\dot{\alpha}}\dot{\alpha} + M_{\dot{\theta}}\dot{\theta} + M_\delta \delta$

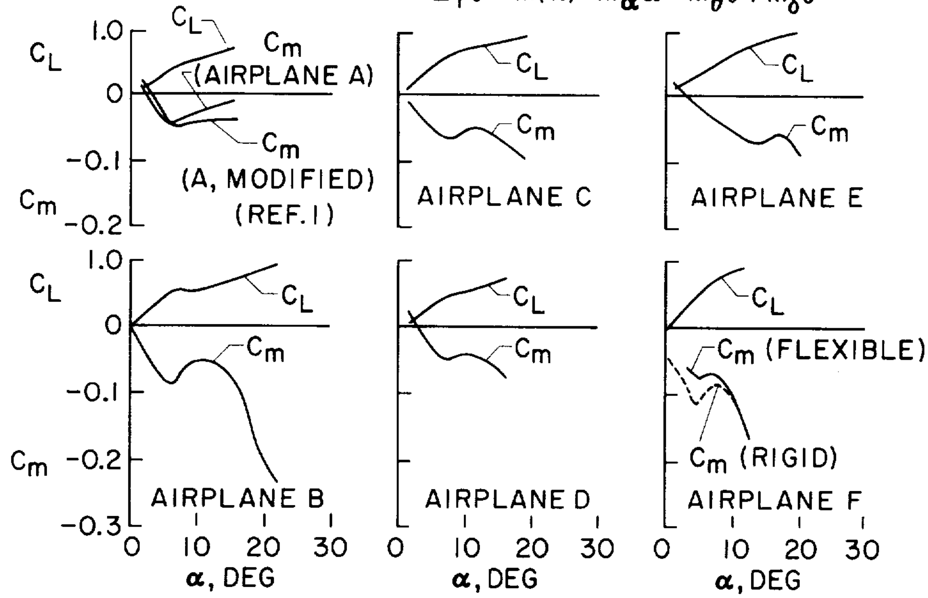

Figure 4

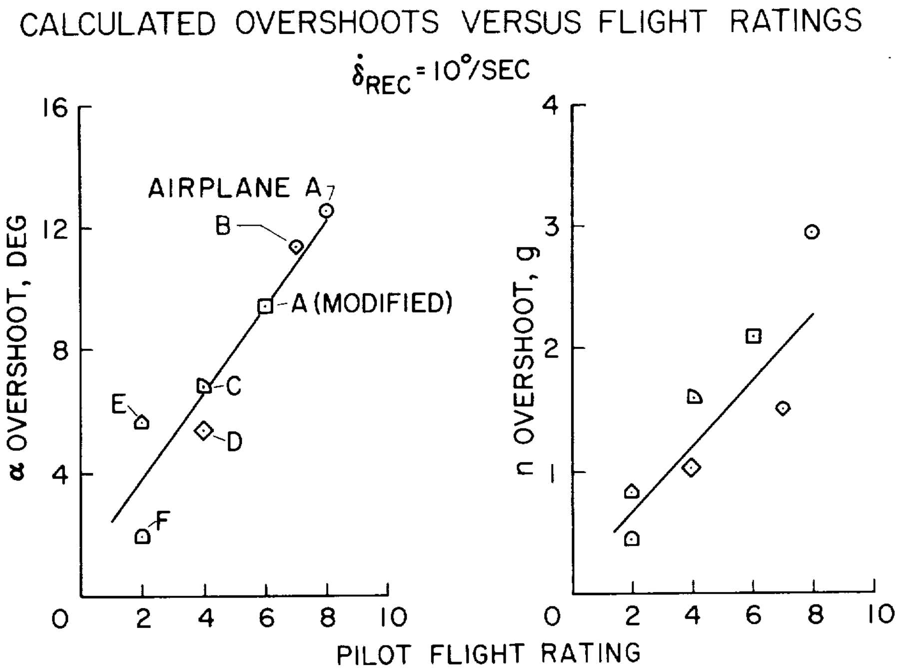

Figure 5

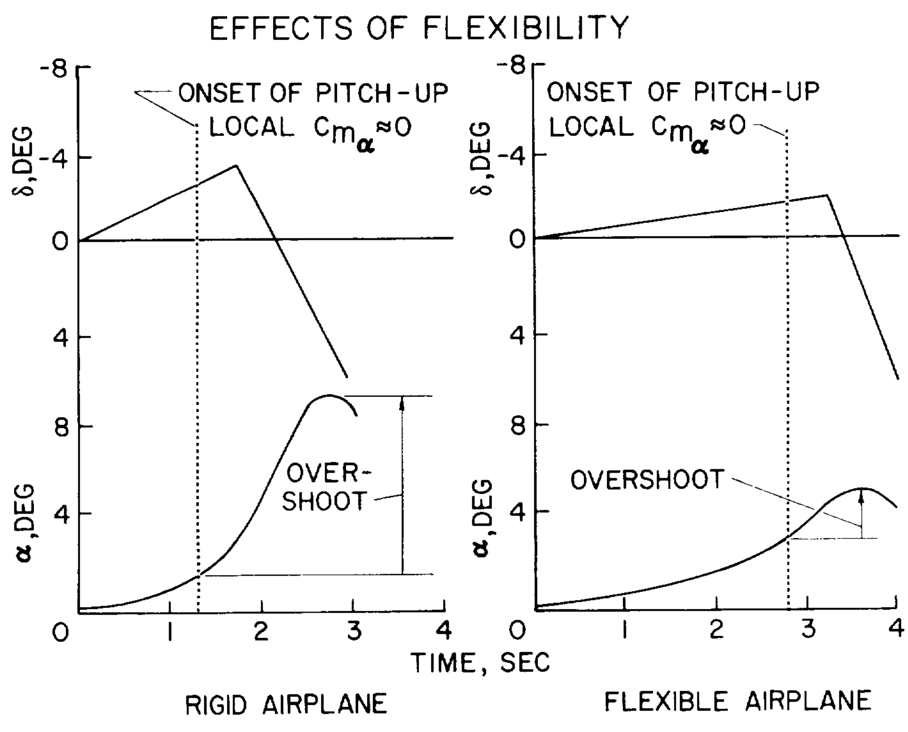

Figure 6

PEAK LOAD FACTOR AND TAIL LOADS
AT 35,000 FEET

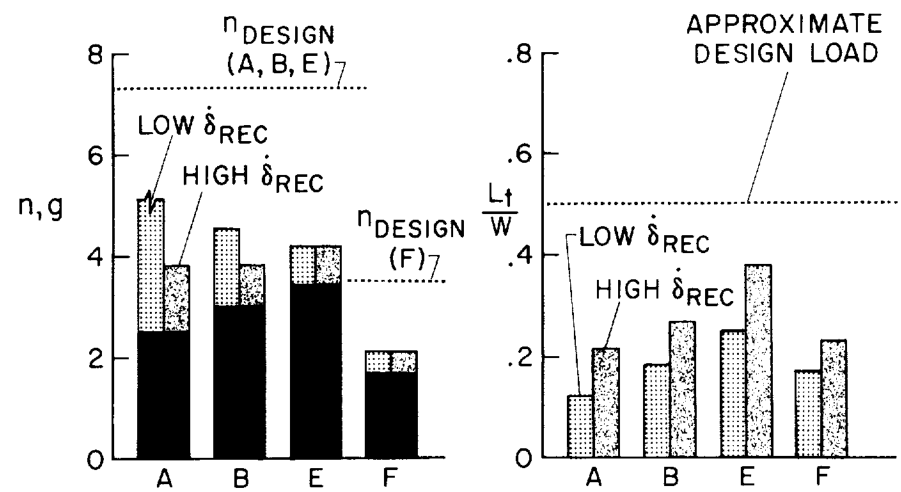

Figure 7

PEAK LOAD FACTOR AND TAIL LOADS
AT LOWER ALTITUDES

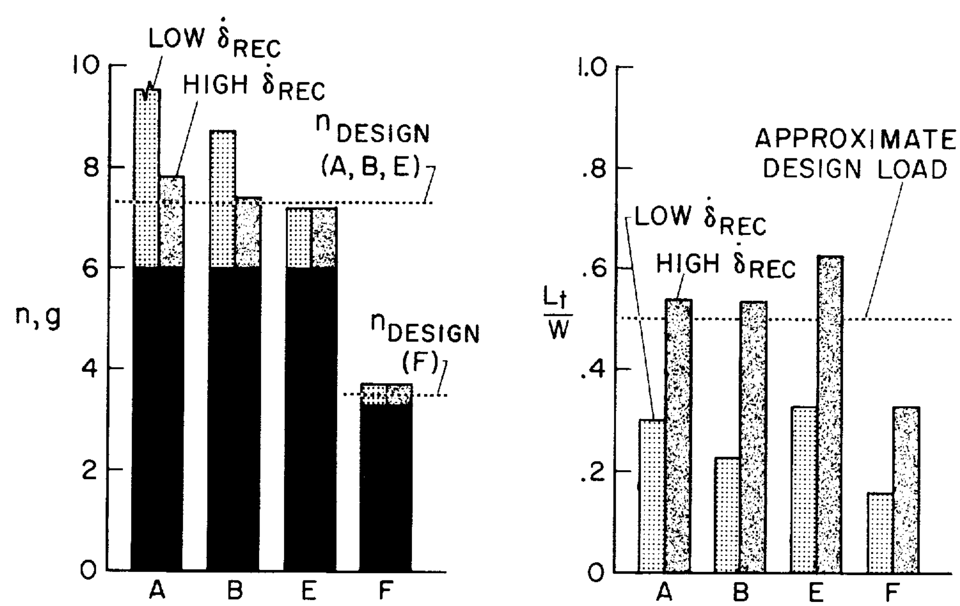

Figure 8

NASA MEMO 3-7-59A
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Copies obtainable from NASA, Washington

1. Stability, Longitudinal - Static (1.8.1.1.1)
2. Stability, Longitudinal - Dynamic (1.8.1.2.1)
3. Control, Longitudinal (1.8.2.1)
4. Loads, Maneuvering - Wings (4.1.1.1.2)
5. Loads, Maneuvering - Tail (4.1.1.2.2)

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